# TARDEC

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THE NATION'S LABORATORY FOR ADVANCED AUTOMOTIVE TECHNOLOGY

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TARDEC

Ride Motion Simulator Seat Comparison
Experiments in Support of the National
Automotive Center's COMBATT Program

November 1999

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**13. ABSTRACT** *(Maximum 200 Words)*

This report describes and documents only the work performed by the Motion Base Technologies (MBT) Team in the Physical Simulation Laboratory using the Ride Motion Simulator (RMS). The MBT Team conducted an experiment using the RMS for the National Automotive Center (NAC) in support of the COMmercially BAsed Tactical Truck (COMBATT) program. The NAC is exploring the feasibility of using and modifying commercially based trucks for military applications. A primary goal of this feasibility is to match or exceed the performance characteristics of the High Mobility Multi-Purpose Wheeled Vehicle (HMMWV.) The purpose of this experiment was to compare different seats. These seats were mounted to the RMS and put under motion while being occupied by humans. These occupants sat on a seat cushion accelerometer and rested their back on another. Responses were recorded for each run. This report only represents the work done on the RMS during these experiments and does not incorporate any findings of the other parties involved. The experiments were conducted by the MBT Team (AMSTA-TR-VP), in Building 215, at TARDEC from April to September 1999.

**14. SUBJECT TERMS**

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# PREFACE

This report documents the work performed from April – September 1999 in the Physical Simulation Laboratory (PSL) for the Ride Motion Simulator (RMS) by the Motion Base Technologies (MBT) Team. Questions regarding the Ride Motion Simulator are to be referred to the U.S. Army Tank-automotive Research, Development, and Engineering Center (TARDEC), ATTN: Motion Base Technologies Team (AMSTA-TR-VP), Bldg. 215, Warren, MI 48397-5000, Telephone: AUTOVON/DSN 786-5032, Commercial (810) 574-5032, FAX (810) 574-8667.

This project would not have come about if it were not for the National Automotive Center (NAC) of TARDEC who financially supported the work. Thank you to Hal Almand of the NAC for this. Special thanks goes out to those who played an important role in the many facets of this study. Some of whom include: Dr. Alexander Reid, electrical engineer, who helped prepare the GM road profiles for the simulator, Mike Reininger, electrical technician, who installed all the accelerometers to the RMS platform, installed and operated the data acquisition system and Ron Smith, mechanical technician, who fabricated the mounting fixtures to hold the different seats to the platform, installed safety seat belts to each seat as well as mounted other pieces of hardware to the cab necessary to complete the safety man-rating. Lastly, thank you to Harry Zywiol and Mark Brudnak who volunteered as subjects for these experiments.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

# 1.0 INTRODUCTION

The National Automotive Center (NAC) of TARDEC is exploring the feasibility of using and modifying commercially based trucks for military applications. A primary goal of this feasibility is to match or exceed the performance characteristics of the High Mobility Multi-Purpose Wheeled Vehicle (HMMWV.) The NAC has teamed up with ERIM International, Ann Arbor, MI, University of Michigan Transportation Research Institute (UMTRI) and the Motion Base Technologies (MBT), of TARDEC. The NAC Team has requested the MBT Team to perform key experiments to support driver seat characterization utilizing the Ride Motion Simulator (RMS), see Figure 1. The NAC supplied the MBT Team with several seats from vehicles to include a HMMWV and Ford. General Motors graciously lent TACOM their seat cushion accelerometers to use during all the experiments. In return, General Motors (GM) supplied a GM truck seat to be tested along with the other seats. The MBT Team mounted these seats, one at a time, on their high fidelity six degree-of-freedom (DOF) motion simulator. Human subjects experienced controlled motions representative of a COMmercially BAsed Tactical Truck (COMBATT) vehicle while sitting on a seat in the RMS. A number of controlled motion drives were given to the manned platform. A unique transfer function will be determined for each seat/human test motion.

This report describes and documents the work performed in the Physical Simulation Laboratory (PSL) for the RMS by the MBT Team. This report does not incorporate the findings of UMTRI. The tests were executed at TARDEC by the MBT Team, in building 215 from 1 April to 17 September, 1999. The first series of tests were conducted from 1-28 April 1999 and the second series of tests were conducted 1-17 September 1999.

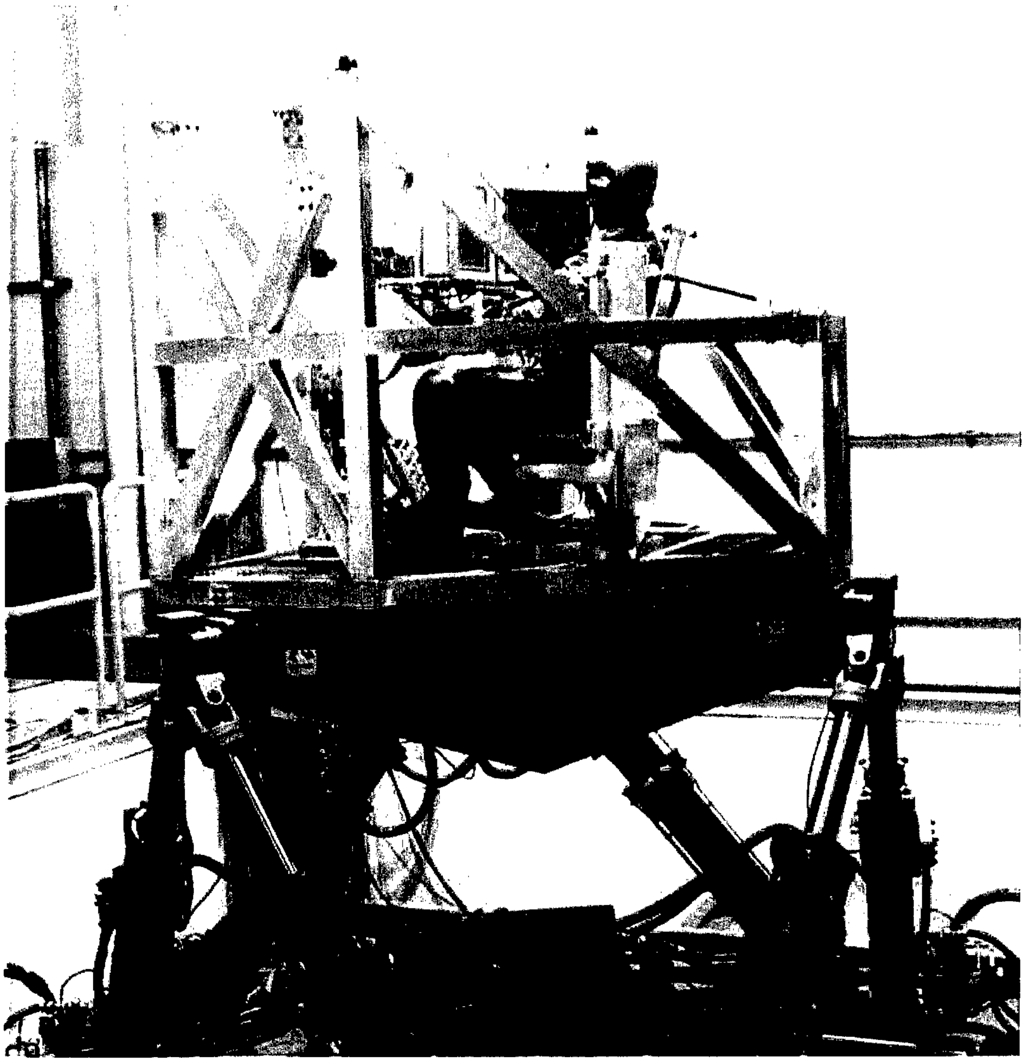

FIGURE 1. RIDE MOTION SIMULATOR

## 2.0 OBJECTIVES

The purpose of this laboratory experiment was to determine the seat/human transfer function for various seats such as the HMMWV, Ford and GM Trucks. UMTRI modeled this data in order to use it in their overall COMBATT model. To accomplish this,

of-freedom, white noise in all six degrees-of-freedom and three GM road profiles. The GM road profiles consisted of reproductions of rides on two test roads. One was measured on the GM Swells ride road and the other on the GM Spalled Concrete road. The Swells ride has more energy in the low frequency range of 0-5 Hz with a lot of roll and pitch, whereas, the Spalled Concrete ride consists of broken pavement and has more energy in the higher frequency range of 10 – 20 Hz. The R12 GM ride consists of "chuck holes" and has its energy evenly distributed from 0 – 25 Hz.

The results of this study will ultimately assist the NAC, ERIM and UMTRI in carefully modeling the seats with controlled experiments using a special software package. With the results of their study, they could design a seat that duplicates the exact characteristics in actual seats to make for a more effective ride.

## 3.0 CONCLUSIONS

The RMS was successful in reaching the objective of this experiment. Two sets of experiments were run from the April to September 1999 time frame. The first set of experiments were conducted utilizing the translational axes for the test inputs and the second set of experiments utilized the rotational axes for the test inputs. The same set of acceleration data was recorded for both sets of experiments. Two humans were used as subjects as well as a water bottle and an anthropomorphic (non-instrumented) dummy. There were over 400 successful runs with all subjects. All motion data were recorded per the test plan.

The tests involved recording the accelerations imparted on various seats while under a vibration environment. The data was sufficient enough for UMTRI to determine the transmissibility of the vibration to the passenger in each degree of freedom from the seat cushion and the back cushion. The subjects were exposed to swept sines, white noise in all the degrees of freedom and three GM ride profiles. The inputs to the first and second sets of experiments are listed in Table 1 and 2 respectively.

TABLE 1. EXPERIMENT 1 INPUTS

| Drive# | Test Condition | Motion Amplitude | SeatType | Subject |
|---|---|---|---|---|
| 1 | Vertical , white noise | 0.20 g rms | H, F, G | 1 - 4 |
| 2 | | 0.26 g rms | H, F, G | 1 - 4 |
| 3 | Lateral, white noise | 0.15 g rms | H, F, G | 1 - 4 |
| 4 | | 0.20 g rms | H, F, G | 1 - 4 |
| 5 | Longitudinal, white noise | 0.15 g rms | H, F, G | 1 - 4 |
| 6 | | 0.20 g rms | H, F, G | 1 - 4 |
| 7 | Vertical, sine weep | 0.14 g peak | H, F, G | 1 - 4 |
| 8 | | 0.30 g peak | H, F, G | 1 - 4 |
| 9 | | 0.50 g peak | H, F, G | 1 - 4 |
| 10 | Lateral, sine sweep | 0.10 g peak | H, F, G | 1 - 4 |
| 11 | | 0.14 g peak | H, F, G | 1 - 4 |
| 12 | | 0.25 g peak | H, F, G | 1 - 4 |
| 13 | Longitudinal, sine sweep | 0.14 g peak | H, F, G | 1 - 4 |
| 14 | | 0.25 g peak | H, F, G | 1 - 4 |
| 15 | | 0.30 g peak | H, F, G | 1 - 4 |
| 16 | 6 DOF white noise xyzrpy | {0.23g, 0.17g, 0.14g, (rms) .725r/s$^2$, .76r/s$^2$, .638r/s$^2$} | H, F, G | 1 - 4 |
| 17 | 6 DOF white noise xyzrpy | {0.16g, 0.13g, .078g, (rms) .56r/s$^2$, .50r/s$^2$, .50r/s$^2$} | H, F, G | 1 - 4 |

H = HMMWV seat, F = Ford seat, G = GM seat

Subjects = Water Bottle, Dummy, Harry Zywiol, Mark Brudnak

TABLE 2. EXPERIMENT 2 INPUTS

| Drive# | Test Condition | Motion Amplitude | SeatType | Subject |
|---|---|---|---|---|
| 1 | Roll , white noise | 0.55 $r/s^2$ rms | H, F, G | 1 - 3 |
| 2 | | 0.76 $r/s^2$ rms | H, F, G | 1 - 3 |
| 3 | | 1.06 $r/s^2$ rms | H, F, G | 1 - 3 |
| 4 | Pitch, white noise | 0.40 $r/s^2$ rms | H, F, G | 1 - 3 |
| 5 | | 0.63 $r/s^2$ rms | H, F, G | 1 - 3 |
| 6 | | 0.84 $r/s^2$ rms | H, F, G | 1 - 3 |
| 7 | Yaw, white noise | 0.27 $r/s^2$ rms | H, F, G | 1 - 3 |
| 8 | | 0.45 $r/s^2$ rms | H, F, G | 1 - 3 |
| 9 | | 0.61 $r/s^2$ rms | H, F, G | 1 - 3 |
| 10 | Roll, sine weep | 0.63 $r/s^2$ pk | H, F, G | 1 - 3 |
| 11 | | 0.85 $r/s^2$ pk | H, F, G | 1 - 3 |
| 12 | | 1.28 $r/s^2$ pk | H, F, G | 1 - 3 |
| 13 | Pitch, sine sweep | 0.63 $r/s^2$ pk | H, F, G | 1 - 3 |
| 14 | | 0.85 $r/s^2$ pk | H, F, G | 1 - 3 |
| 15 | | 1.28 $r/s^2$ pk | H, F, G | 1 - 3 |
| 16 | Yaw, sine sweep | 0.63 $r/s^2$ pk | H, F, G | 1 - 3 |
| 17 | | 0.85 $r/s^2$ pk | H, F, G | 1 - 3 |
| 18 | | 1.28 $r/s^2$ pk | H, F, G | 1 - 3 |
| 19 | 12 mile vehicle data | (20 seconds in duration) | H, F, G | 1 thru 3 |
| 20 | Swells vehicle data | (38.9 seconds in duration) | H, F, G | 1 thru 3 |
| 21 | Spalled vehicle data | (23.3 seconds in duration) | H, F, G | 1 thru 3 |

H = HMMWV seat, F = Ford seat, G = GM seat
Subjects = dummy, Harry Zywiol, Mark Brudnak

## 4.0 RECOMMENDATIONS

We recommend that further work on seat testing be done using the RMS. This particular test created a foundation for short and long-term motion base experiments involving seat with human testing. Many more experiments can be conducted to gain knowledge in military and commercial seat design for passenger ride comfort. Studies can be conducted on seat damping, comparison between foam and spring seats, new seat materials, and human sensitivity. The RMS offers great flexibility in test configurations through its reconfigurable cab and high modularity and networking to other computers. The RMS also provides a reconfigurable cab to support almost any ground vehicle as well as next-generation or future system concepts in regards to seating orientations. The RMS utilizes computer generated imagery for realistic displays of battlefield and target environments or just simply terrain data.

This experiment utilized a data acquisition system by MEGADAC. Although this system proved to do the job, it is recommended to use a more sophisticated data acquisition system in the future. The MBT Team has already acquired a VXI-based data acquisition system from Kinetic Systems Corporation (KSC) for future data acquisition.

This experiment was successful because of the intense pre-test preparation performed by all participants.

# 5.0 DISCUSSION/TESTING

## 5.1 System Description and Characterization

### 5.1.1 System Description

The RMS is a six-degree-of-freedom simulator capable of recreating the ride of any ground vehicle. It is fundamentally a platform mounted to six actuators and capable of very high motion fidelity. A reconfigurable cab is mounted on the platform where different seating configurations can be easily created and simulated. Investigations can be conducted on human tolerance to vibrations, or task performances of subjects in a vibrational environment.

The RMS is comprised of the following major subsystems:

- -Hexapod
- -Cab
- -Hydraulic Supply and Distribution
- -Electronic Controls
- -Controller Software

The RMS Cab was designed with the intent that it could be easily reconfigured to replicate a number of military or commercial ground vehicles. The Cab was also designed as an open framework to accommodate the need to mount a wide variety of components associated with these vehicles. The RMS is based upon the Stewart platform style of motion platform design. It is also commonly referred to as a hexapod since it uses six linear actuators to connect a triangular fixed base with a triangular motion platform. Through control of the six actuators, this mechanism provides for independent or simultaneous motion of the platform in the six natural DOF. The electronic controls act as an interface between a personal computer and the RMS. The hydraulic supply and distribution subsystem is composed of the hydraulic power unit (HPU), the hydraulic service manifold (HSM), and the hydraulic distribution manifolds. The HPU is located in a separate room from the RMS and provides the hydraulic power to the actuators, the HSM provides local control of the main hydraulic power supply to the RMS and the

manifolds distribute the hydraulic power to the six hexapod actuators. The electronic controls consist of a Digital Controller. It has three main parts; the Operator Interface (personal computer), the Real-Time Controller and the Control Software. The Operator Interface consists of an IBM compatible Pentium 450 MHz computer. The user utilizes a custom interactive program to define, select, start and stop a program on the simulator. The MTS 498 Real-Time Controller provides closed-loop control of system motion and consists of a VME computer and digital and analog signal conditioning. The Control Software provides programming and feedback summing to ensure faithful reproduction of the desired waveform so that accurate tests can be conducted and evaluated.

### 5.1.2 Tuning

The RMS was tuned before any experiments took place. Frequency responses were plotted and viewed at the –3db point to ensure the bandwidth of all degrees of freedom were tuned to at least 30 Hz. Before all manned experiments, these tuning parameters were loaded in. The three variable servo control loops were tuned by adjusting the gain and lead parameters where needed. Anti-resonators (notches) were used to remove any specimen and/or simulator resonances. For the experiments that involved using white noise as the input, it was necessary to determine ahead of time the actual input required from the simulator in order to achieve a particular needed input to the occupant. Table 3 shows a list of inputs and outputs that do not equal. The inputs are the values from the simulator's built-in function generator used to get the particular rms value as input to the occupant. These rms values were requested by UMTRI for the experiments. To determine the actual simulator input, a Hewlett Packard Dynamic Signal Analyzer was used to graph a transfer function of the signal and then ultimately determine the rms value. For each experiment requiring a white noise input, the test operator used the values from the table to achieve the necessary rms value for the occupant to experience.

TABLE 3. WHITE NOISE INPUTS

| All 6 Axes | Input | Output |
|---|---|---|
| X (longitudinal) | 1.45 g | 0.23 g rms |
| Y (lateral) | 0.45 g | 0.17 g rms |
| Z (vertical) | 0.90 g | 0.14 g rms |
| Roll | 230 $d/s^2$ | 0.725 $r/s^2$ rms |
| Pitch | 175 $d/s^2$ | 0.76 $r/s^2$ rms |
| Yaw | 120 $d/s^2$ | 0.638 $r/s^2$ rms |
| | | |
| **All 6 Axes** | **Input** | **Output** |
| X (longitudinal) | 1.0 g | 0.16 g rms |
| Y (lateral) | 0.3 g | 0.13 g rms |
| Z (vertical) | 0.45 g | 0.078 g rms |
| Roll | 175 $d/s^2$ | 0.56 $r/s^2$ rms |
| Pitch | 100 $d/s^2$ | 0.50 $r/s^2$ rms |
| Yaw | 120 $d/s^2$ | 0.50 $r/s^2$ rms |
| | | |
| **Single Axis** | **Input** | **Output** |
| Z (vertical) | 1.5 g | 0.20 g rms |
| Z (vertical) | 1.8 g | 0.26 g rms |
| | | |
| X (longitudinal) | 1.0 g | 0.15 g rms |
| X (longitudinal) | 1.45 g | 0.20 g rms |
| | | |
| Y (lateral) | 1.0 g | 0.15 g rms |
| Y (lateral) | 1.45 g | 0.20 g rms |

### 5.1.3 Modeling

The RMS has the ability to play out a defined terrain file to reproduce a particular ride. The file must be in MATLAB binary format. The simulated road profiles used were reproductions of automotive test courses from GM. Table 2 lists the simulated terrains used along with their duration time. The terrains were chosen to provide realistic simulated vehicle dynamic motion over particular terrains.

Remote Parameter Control (RPC) was used to determine and build the Swept Sine commands for the RMS in this experiment. The frequency of the swept sines ranged

from 0.5 Hz to 30 Hz with a constant amplitude. The various swept sine inputs are listed in Tables 1 and 2.

An alternative method for determining the RMS drive commands is to use field or proving ground recorded data and "play" these data into the simulator. This method can produce accurate simulator motion dynamics but was not chosen for a number of reasons mainly due to extensive cost and time required for an instrumentation and data collection task.

### 5.1.4 Data Acquisition

This experiment employed the use of a data acquisition system called the MEGADAC 5406DC. The specifications of the data acquisition system are as follows:

Data Acquisition System: MegaDac 5406DC
ADC quantization: 16 bit
Sample Rate: 750 samples/second
Filter Cut-off Frequency: 200 Hz
Filter brand and model: MegaDac, 8-pole Butterworth, low-pass

The MBT Team collected acceleration data from the simulator and from accelerometers mounted on the RMS platform and in the seat and back pads touching the subjects. There were a total of 20 channels recorded. These are listed in Table 4. The purpose of the Physical Simulation data acquisition system was to record motion simulator response data using linear accelerometers, angular rate transducers, and linear displacement transducers.

This suite of sensors provided the simulator operator and experimentalist with a complete record of simulator and ride motion responses. See Table 4 for the type of sensors used.

TABLE 4. DATA ACQUISITION

| Megadac Channel | Transducer | Full scale value | Amp gain | Model/ Serial # |
|---|---|---|---|---|
| 0. Vertical table acceleration | RMS | 5g | 5 V/G | N/A |
| 1. Long table acceleration | RMS | 5g | 5 V/G | N/A |
| 2. Lat table acceleration | RMS | 5g | 5 V/G | N/A |
| 3. Roll table acceleration | RMS | 20 r/s2 | 2 V/G | N/A |
| 4. Pitch table acceleration | RMS | 20 r/s2 | 2 V/G | N/A |
| 5. Yaw table acceleration | RMS | 20 r/s2 | 2 V/G | N/A |
| 6. Vert seat floor accel (Front Rt) | Accelerometer | 5g | 20 | 597856 |
| 7. Long seat floor accel (Front Rt) | Accelerometer | 5g | 20 | 597857 |
| 8. Vert seat floor accel (Rear Rt) | Accelerometer | 5g | 20 | 597849 |
| 9. Vert seat floor accel (Rear Left) | Accelerometer | 5g | 20 | 597858 |
| 10. Long seat floor accel (Rear Left) | Accelerometer | 5g | 20 | 597855 |
| 11. Lat seat floor accel (Rear Left) | Accelerometer | 5g | 20 | 597854 |
| 12. Long seat acceleration butt | X seat pan | 1.345 | 1 | GM15366 |
| 13. Lat seat acceleration butt | Y seat pan | 1.348 | 1 | GM15365 |
| 14. Vert seat acceleration butt | Z seat pan | 1.328 | 1 | GM15458 |
| 15. Vert 2 Seat acceleration butt | Z2 seat pan | 1.351 | 1 | GM12708 |
| 16. Long back acceleration | X seat back | 107.1 | 10 | GM_446X |
| 17. Lat back acceleration | Y seat back | 105.5 | 10 | GMCY446 |
| 18. Vert back acceleration | Z seat back | 104.9 | 10 | GMCZ446 |

Accelerometers were mounted on the RMS platform approximately ½ inch to 1½ inches from the edge of the seat mounting plate. (See Figure 2.)

The linear accelerometers were used to produce the vertical acceleration data to determine the seat/human transfer function of the various seats for every test run.

The simulator accelerometers provided a recording to ensure the motion base was driven to specification.

Accelerometer pads were used for behind and under the subject and was provided by GM (See Figure 3.) The back pad consisted of a round rubber disk surrounding three accelerometers for the vertical, longitudinal, and lateral positions. The seat pad consisted of a wooden triangular box in a slim seat cushion. The triangular box contained four accelerometers; two vertical, one longitudinal, and one lateral.

Accelerometer pads were used for behind and under the subject and was provided by GM (See Figure 3.) The back pad consisted of a round rubber disk surrounding three accelerometers for the vertical, longitudinal, and lateral positions. The seat pad consisted of a wooden triangular box in a slim seat cushion. The triangular box contained four accelerometers; two vertical, one longitudinal, and one lateral.

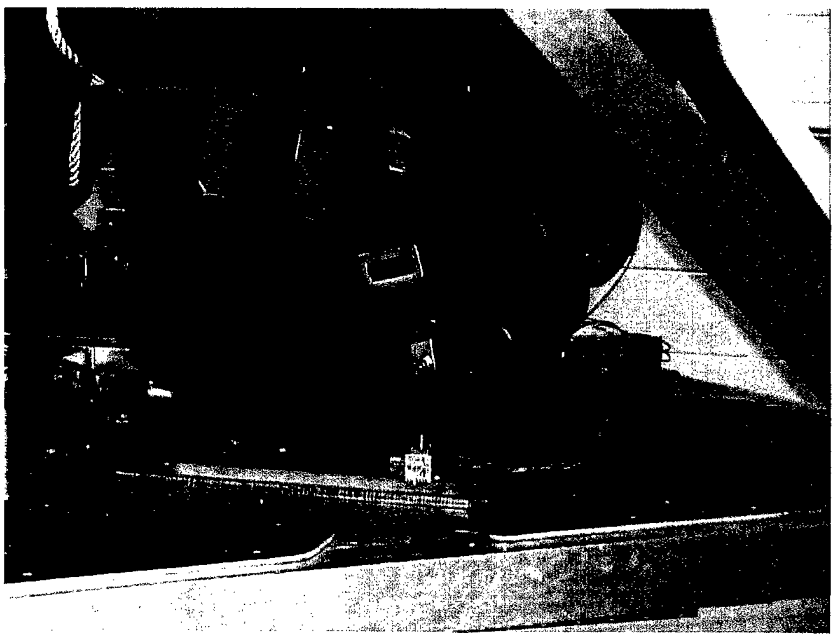

FIGURE 2. ACCELEROMETER PLACEMENT

### 5.2 Safety System

There were numerous built-in safety used to provide protection to test specimens and equipment. The occupant was required to wear 5-point seatbelt harness for their protection. Table 6 lists the limit detectors set and used for every test run conducted on the RMS to ensure the safety of the occupant.

TABLE 5. LIMIT DETECTORS

| **Limit** | **Range** |
|---|---|
| X world position command limit | +/- 2 inches |
| Y world position command limit | +/- 3 inches |
| Z world position command limit | +/- 5 inches |
| Roll world position command limit | +/- 9 degrees |
| Pitch world position command limit | +/- 9 degrees |
| Yaw world position command limit | +/- 9 degrees |
| | |
| X world position limit | +/- 2 inches |
| Y world position limit | +/- 3 inches |
| Z world position limit | +/- 5 inches |
| Roll world position limit | +/- 9 degrees |
| Pitch world position limit | +/- 9 degrees |
| Yaw world position limit | +/- 9 degrees |
| | |
| X world accel command limit | +/- 1.0 g |
| Y world accel command limit | +/- 1.0 g |
| Z world accel command limit | +/- 1.5 g |
| Roll world accel command limit | +/- 385 $d/s^2$ |
| Pitch world accel command limit | +/- 300 $d/s^2$ |
| Yaw world accel command limit | +/- 240 $d/s^2$ |
| | |
| X world accel limit | +/- 1.0 g |
| Y world accel limit | +/- 1.0 g |
| Z world accel limit | + 1.25 g / - 3.25 g |
| Roll world accel limit | +/- 385 $d/s^2$ |
| Pitch world accel limit | +/- 500 $d/s^2$ |
| Yaw world accel limit | +/- 240 $d/s^2$ |
| | |
| X world servo error limit | +/- 5 inches |
| Y world servo error limit | +/- 5 inches |
| Z world servo error limit | +/- 5 inches |
| Roll world servo error limit | +/- 5 degrees |
| Pitch world servo error limit | +/- 5 degrees |
| Yaw world servo error limit | +/- 5 degrees |
| | |

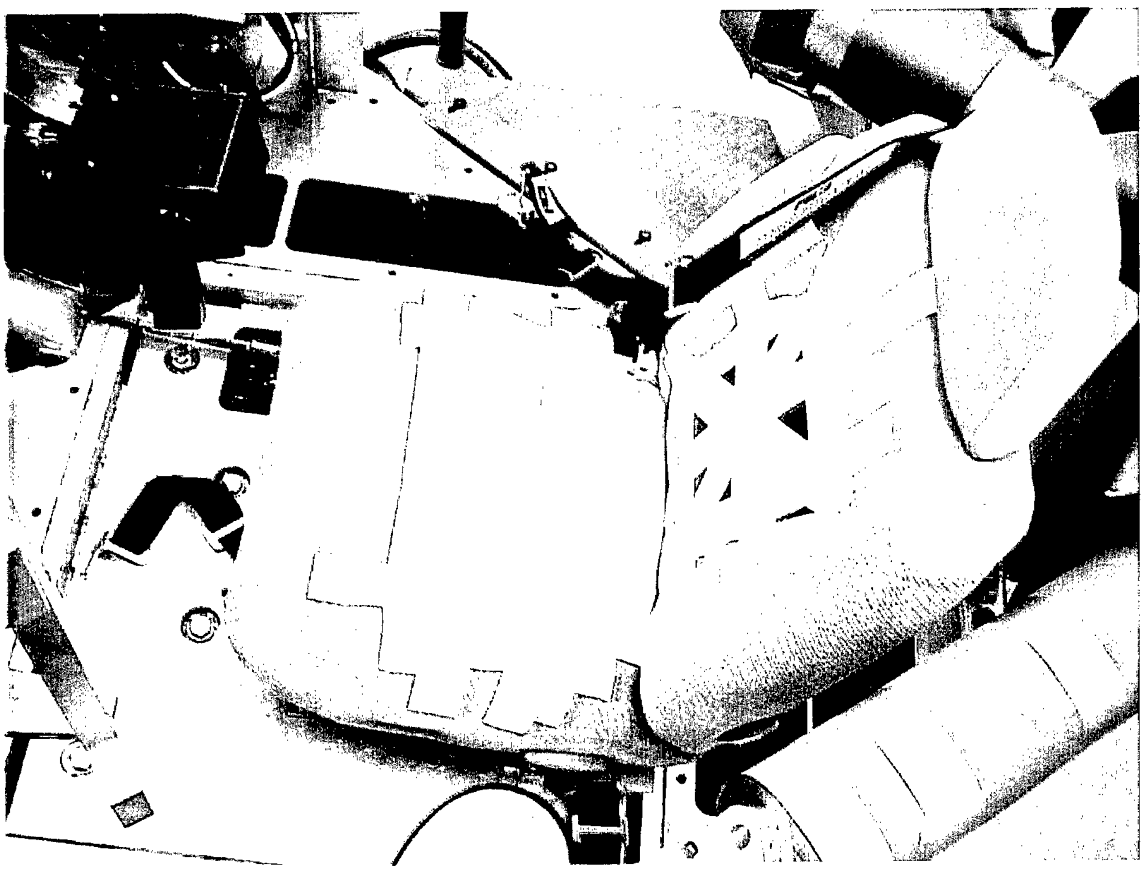

FIGURE 3. GM ACCELEROMETER PAD PLACEMENT

The RMS is man-rated and undergoes a periodic review with the Human Use Committee (HUC) to document the progress of Human Research and Engineering Directorate (HRED) Research, Development, Test and Evaluation (RDTE) activities involving human subjects. The safety system of the RMS also includes an uninterruptible power supply (UPS) which is automatically activated in the event of electrical power failure. The UPS will provide the simulator with backup power for up to 30 minutes. In the case of an interlock detection, all simulator motion is stopped. A Failure and Effects sheet containing all the possible event failures with the RMS along with their necessary actions to be taken is completed and initialed off by the project engineer before every RMS test. For a full description of the safety interlocks, please see the TARDEC report titled "Operator's Manual for the Ride Motion Simulator."

5.3 Test Conduct

The RMS was used for all the experiments. Subjects for the experiments included a water bottle, an anthropomorphic (non-instrumented) dummy, and two humans. The tests inputs were executed per Table 1 and Table 2. The human subjects were required to sit on the seat and grasp the yoke hand station during all the test inputs. All subjects were required to use a 5-point seatbelt harness for their protection. There were a few tests in the second series of experiments where the subjects placed their hands on their laps. This was to investigate any changes in the data being recorded.

The human subjects were shown all the test inputs before they were boarded on the simulator. This showed them what motions they were to expect. It took about 45 minutes to complete all the test inputs for one subject on each seat. A sample run sheet used during the experiments can be seen in Appendix A.

The duration of each of the runs varied. The sine sweeps were 72 seconds in duration whereas the white noise inputs were stopped after 60 seconds. The duration of the GM profiles were all different. The Swells ride was 23 seconds, the Spalled ride 38 seconds and the 12 Mile Road was 20 seconds.

The first set of experiments produced about 200 test runs with data recorded for each. The inputs only included white noise and sine sweeps to the translational axes (that is, vertical, longitudinal, and lateral.) The white noise was used for each translational DOF individually and there were 2 inputs where the white noise was inputted to all 6 DOF.

The second set of experiments produced about 147 test runs with data recorded for each. The water bottle was not used for this set of experiments. The inputs included white noise and sine sweeps to the rotational axes (that is, roll, pitch, and yaw.) There also included three GM profiles listed in Table 2. The test scenario differed from the first set of experiments. This set included adding some weight to the accelerator pads strapped to

the back (3/4 lb.) and bottom (2½ lbs.) of the seat. One subject was also required to place his hands on his lap as opposed to holding on to the controller. This was for the GM seat and subject, Brudnak, only. The scenario for the second set of experiments (Table 2) went as follows:

| | | | |
|---|---|---|---|
| Drive #'s | 1–21 | 3 seats, 2 occupants (Mark, Harry) | 126 runs |
| Drive #'s | 19-21 | 3 seats, dummy only | 9 runs |
| Drive #'s | 2,5,8,19-21 | GM seat only, Mark hands on lap | 6 runs |
| Drive #'s | 22-24 | GM seat only, Mark w/ added wt. | 3 runs |
| Drive #'s | 22-24 | GM seat only, Mark w/o wt. | 3 runs |
| | | Total | 147 runs |

FIGURE 4. FORD SEAT

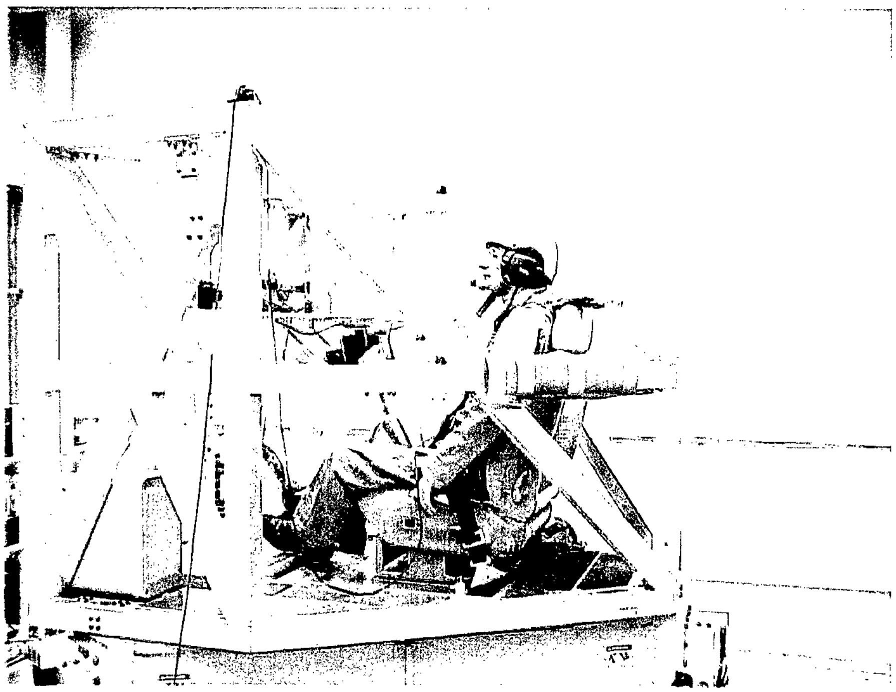

FIGURE 5. GM SEAT

5.4 Analysis

The MBT Team did some analysis on the acceleration data recorded. The absorbed power for many of the runs were calculated from the acceleration feedback data for verification purposes. However, the rest of the analysis for this experiment was quantified by UMTRI.

REFERENCES


1. R. A. Lee and F. Pradko, Analytical Analysis of Human Vibration (680091). Detroit, MI: Society of Automotive Engineers, 1968.

2. MTS Systems, Operation Manual (Job No. 318.01), Eden Prairie, MN,

3. Bosch Automotive Handbook, 3rd Edition, 1993.

ACRONYMS

| | |
|---|---|
| COMBATT | COMmercially BAsed Tactical Truck |
| DOF | Degree of Freedom |
| GM | General Motors |
| HMMWV | High Mobility Multi-Purpose Wheeled Vehicle |
| HRED | Human Research and Engineering Directorate |
| HUC | Human Use Committee |
| Hz | Hertz |
| KSC | Kinetic Systems Corporation |
| MBT | Motion Base Technologies |
| NAC | National Automotive Center |
| PSL | Physical Simulation Laboratory |
| RDTE | Research, Development, and Test Evaluation |
| RMS | Ride Motion Simulator |
| rms | Root Mean Square |
| RPC | Remote Parameter Control |
| TACOM | Tank-automotive and Armaments Command |
| TARDEC | Tank Automotive Research, Development and Engineering Center |
| UMTRI | University of Michigan Transportation Research Institute |
| UPS | Uninterruptible Power Supply |

APPENDIX A

SAMPLE RUN SHEETS

Date: ____________

# Run Sheet for RMS COMBATT

| RUN # | FILENAME: [SUBJECT NAME (3)_SEAT_DRIVE#] | DRIVE # | TEST CONDITION | MOTION AMPLITUDE | SEAT TYPE (H,F,G) | SUBJECT NAME |
|---|---|---|---|---|---|---|
| | | 1 | Vertical, white noise | 0.20 g rms | | |
| | | 2 | " | 0.26 g rms | | |
| | | 3 | Lateral, white noise | 0.15 g rms | | |
| | | 4 | " | 0.20 g rms | | |
| | | 5 | Longitudinal, white noise | 0.15 g rms | | |
| | | 6 | " | 0.20 g rms | | |
| | | 7 | Vertical, sine sweep | 0.14 g pk to pk | | |
| | | 8 | " | 0.3 g pk to pk | | |
| | | 9 | " | 0.5 g pk to pk | | |
| | | 10 | Lateral sine sweep | 0.10 g pk to pk | | |
| | | 11 | " | 0.14 g pk to pk | | |
| | | 12 | " | 0.25 g pk to pk | | |
| | | 13 | Longitudinal sine sweep | 0.14 g pk to pk | | |
| | | 14 | " | 0.25 g pk to pk | | |
| | | 15 | " | 0.3 g pk to pk | | |
| | | 16 | 6 DOF white noise, xyzrpy | {0.23 g, 0.17 g, 0.14 g (rms), 0.725 $r/s^2$, 0.76 $r/s^2$, 0.638 $r/s^2$ } | | |
| | | 17 | " | {0.16 g, 0.13 g, 0.078 g (rms), 0.56 $r/s^2$, 0.50 $r/s^2$, 0.50 $r/s^2$} | | |

{H = HMMWV seat, F = Ford seat, G = GM seat}

<u>Comments:</u>

Wt. Standing ______

Wt. Sitting ______

**Date:** ___________

## Run Sheet for RMS COMBATT 2

| Run # | Drive # | GOOD/ BAD | COMMENTS | SEAT TYPE (H,F,G) | SUBJECT NAME |
|---|---|---|---|---|---|
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{H = HMMWV seat, F = Ford seat, G = GM seat}

Subject:

Wt. Standing _________ Wt. Sitting ___________

Menu of Runs for RMS COMBATT (Experiment 2)

| Drive # | Test Condition | Motion Amplitude | Function Generator Input @ 50Hz |
|---|---|---|---|
| 1 | Roll, white noise | 0.55 $r/s^2$ rms | 190 $d/s^2$ |
| 2 | Roll, white noise | 0.76 $r/s^2$ rms | 265 $d/s^2$ |
| 3 | Roll, white noise | 1.06 $r/s^2$ rms | 365 $d/s^2$ |
| 4 | Pitch, white noise | 0.40 $r/s^2$ rms | 134 $d/s^2$ |
| 5 | Pitch, white noise | 0.63 $r/s^2$ rms | 200 $d/s^2$ |
| 6 | Pitch, white noise | 0.84 $r/s^2$ rms | 280 $d/s^2$ |
| 7 | Yaw, white noise | 0.27 $r/s^2$ rms | 110 $d/s^2$ |
| 8 | Yaw, white noise | 0.45 $r/s^2$ rms | 175 $d/s^2$ |
| 9 | Yaw, white noise | 0.61 $r/s^2$ rms | 230 $d/s^2$ |
| 10 | Roll, sine sweep | .63 $r/s^2$ pk | |
| 11 | Roll, sine sweep | .85 $r/s^2$ pk | |
| 12 | Roll, sine sweep | 1.28 $r/s^2$ pk | |
| 13 | Pitch, sine sweep | .63 $r/s^2$ pk | |
| 14 | Pitch, sine sweep | .85 $r/s^2$ pk | |
| 15 | Pitch, sine sweep | 1.28 $r/s^2$ pk | |
| 16 | Yaw, sine sweep | .63 $r/s^2$ pk | |
| 17 | Yaw, sine sweep | .85 $r/s^2$ pk | |
| 18 | Yaw, sine sweep | 1.28 $r/s^2$ pk | |
| 19 | 'R12_GM' drive file (20 sec) | | |
| 20 | 'SPC_GM' drive file (38.9 sec) | | |
| 21 | 'SWL_GM' drive file (23.3 sec) | | |
| 22 | Longitudinal, white noise | 0.20 g rms | 1.453 g @ 30 Hz |
| 23 | Lateral, white noise | 0.20 g rms | 1.453 g @ 30 Hz |
| 24 | Vertical, white noise | 0.26 g rms | 1.723 g @ 30 Hz |
| 25 | X sinesweep (.3 pk to pk) | | |
| 26 | Y sinesweep (.25 pk to pk) | | |
| 27 | Z sinesweep (.5 pk to pk) | | |

APPENDIX B

TEST PLAN

# Test Plan for the Dynamic Characterization of COMmercially Based Tactical Truck (COMBATT) Driver Seats.

Prepared by:

**Motion Base Technologies Team**
**AMSTA-TR-VP**
**U.S. Army Tank-Automotive Research Development and Engineering Center**
**810-574-5032**

March 1, 1999

**Introduction.**

The National Automotive Center (NAC) is exploring the feasibility of using and modifying commercially based trucks for military applications. A primary goal of this feasibility is to match or exceed the performance characteristics of the HMMVW. The NAC has teamed up with ERIM International, Ann Arbor, MI, University of Michigan Transportation Research Institute (UMTRI) and Motion Base Technologies (MBT), of TARDEC. The NAC team has requested Motion Base Technologies to perform key experiments to support driver seat characterization utilizing the Ride Motion Base Simulator. The NAC will supply the MBT with several seats from vehicles to include HMMWV, Ford truck and perhaps others as well. The MBT will mount these seats, one at a time on a high fidelity six degree-of-freedom motion simulator. Human subjects will sit on the seats and be experienced to controlled motions representative of the COMBATT vehicle. A sensor suite will be installed on the seats and motion simulator to determine the transfer function of the seat. A number of controlled motion drives will be given to the seat/human platform. A unique transfer function will be determined for each seat/human test motion.

The intent of this plan is to clarify the roles of the Motion Base Technologies Office, TARDEC for the National Automotive Center. This plan may be used in conjunction with written plans from UMTRI and ERIM with the goal of a successful experiment useful to the National Automotive Center, TARDEC. The experiments are expected to begin in the Motion Base Laboratory, TARDEC, in late March 1999.

**Responsibilities.**

MBT will:

- install seats and provide a Ride Motion Simulator
- install data acquisition
- synthesize drive file development necessary to control the motion base
- conduct seat experiments by operating the Ride Motion Simulator
- collect data from the experiments and provide to UMTRI and ERIM
- provide human volunteer(s) to ride in the simulator

UMTRI will:

- provide test specifications and guidance on the experiments
- analyze the data, determine transfer functions, interpret the results
- provide human volunteer(s) to ride in the simulator
- provide simulation drive files

ERIM will:

- provide the seats
- provide experiment guidance and consulting
- interpret the results
- provide human volunteer(s) to ride in the simulator

Motion Simulator

The Ride Motion Simulator will be used for all experiments. It is a six degree-of-freedom motion base with very high motion fidelity. It offers many useful capabilities unique to this application including safety, high performance, and ease of use. Figure 1 illustrates the simulator.

Key Features:

Axes: 6; Vertical, Longitudinal, Lateral, Roll, Pitch, Yaw
Displacement: +- 20 inches, +- 20 degrees
Acceleration: +- 2 g, +- 1150 degrees/second(2)
Frequency response: >30 hertz
Payload: 600 pounds, re-configurable
Safety: U.S. Army Man-rated and Safety Certified, Numerous control and feedback safety interlocks.

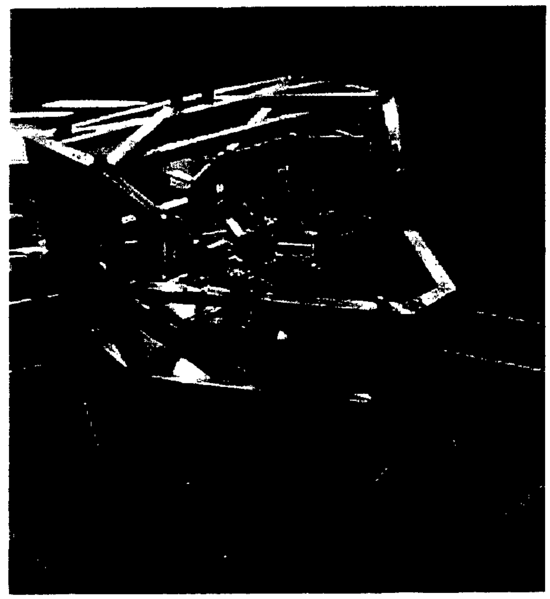

Figure 1

The simulator will be pay-loaded with the seat, volunteer, and yoke hand station. The subject will be required to sit on the seat and grasp the yoke hand station. This simulates the most common driving position. The simulator cab contains E-stop and motion consent switches. Thus the volunteer can, if necessary, terminate the motion. The volunteer will wear overalls (provided) and a wireless headset outfitted to a helmet. Thus, the researcher, volunteer, and simulator operator will be in constant communication with each other.

**Test Scenarios**

Each of the seat/human subject combinations will be subject to several different types of controlled motion inputs. The input specifications were provided by UMTRI and are summarized in Table 1. All motion control signals will be carefully analyzed before commanding them to the RMS. Initially, The RMS will be operated without human

occupants to verify the motions are not injurious to the occupant. RMS accelerations will be compared to the shock and vibration literature to ensure safety to the occupant.

Table 1. Experiment Inputs

| **Drive #** | **Test Condition** | **Motion Amplitude** | **Seat Type** | **Subject #** |
|---|---|---|---|---|
| 1 | vertical , white noise | 0.2g rms | H, F, G | 1 thru 5 |
| 2 | | 0.5 g rms | H, F, G | 1 thru 5 |
| 3 | | 0.75 g rms | H, F, G | 1 thru 5 |
| 4 | vertical, sine weep | 0.3 g pk to pk | H, F, G | 1 thru 5 |
| 5 | | 0.7 g pk to pk | H, F, G | 1 thru 5 |
| 6 | | 1.0 g pk to pk | H, F, G | 1 thru 5 |
| 7 | lateral sine sweep | 0.14 g pk to pk | H, F, G | 1 thru 5 |
| 8 | | 0.35 g pk to pk | H, F, G | 1 thru 5 |
| 9 | | 0.7 g pk to pk | H, F, G | 1 thru 5 |
| 10 | longitudinal sine sweep | 0.14 g pk to pk | H, F, G | 1 thru 5 |
| 11 | | 0.35 g pk to pk | H, F, G | 1 thru 5 |
| 12 | | 0.7 g pk to pk | H, F, G | 1 thru 5 |
| 13 | 6 DOF white noise xyzrpy | 0.2g, 0.1g, 0.1g, (rms) 0.7r/s2, 0.7r/s2, 0.5r/s2 | H, F, G | 1 thru 5 |
| 14 | | 0.4g, 0.2g, 0.2g (rms) 1.4r/s2, 1.4r/s2, 1.0r/s2 | H, F, G | 1 thru 5 |
| 15 | | 0.6g, 0.3g, 0.3g, (rms) 2.1r/s2, 2.1r/s2, 1.5r/s2 | H, F, G | 1 thru 5 |
| 16 | 12mile vehicle data | | H, F, G | 1 thru 5 |
| 17 | Swells vehicle data | | H, F, G | 1 thru 5 |
| 18 | Spalled concrete data | | H, F, G | 1 thru 5 |
| 19 | RMS Course(s) | | H, F, G | 1 thru 5 |
| | | | | |

H = HMV, F = Ford, G = GM (possibly)

Each subject will be run thru each test. So, for 5 subjects there will be 5*19 = 95 experiments per seat. One week is estimated to complete 5 subjects for 1 seat. The test sequence is:

- Volunteer (1) board simulator.
- Volunteer (1) experiences all 19 drive files. Breaks will be taken as necessary (approximately once every hour of simulator operation).
- Repeat two drive files on volunteer (1) for repeatability purposes.
- Repeat with the next volunteer.

The MBT Standard Operating Procedure (SOP) will be applied. These procedures follow the man-rating protocol for safety.

**Data Acquisition.**

Each seat and simulator will be instrumented with accelerometers. To speed up the instrumentation preparation effort, a General Motors seat pan and back accelerometer package will be mounted to the seat. This is a modular package used for characterizing human/seat measurements. General Motors will loan TARDEC the seat accelerometer package. The location of each of the transducers will be documented using measured positions and photographs. Specifications of the data acquisition system are as follows:

Data Acquisition system: Megadac 5406DC
ADC quantization: 16 bit
Sample rate: 750 samples/second
Filter Cutoff Frequency: 200 hertz
filter brand and model: Megadac, 8-pole Butterworth, Low pass.
Frequency range of interest: 0 - 30 hertz

| **Megadac Channel** | **Transducer** | **Full scale value** | **Amp gain** | **Model/ Serial #** |
|---|---|---|---|---|
| 0. Vertical table acceleration | RMS | 5g | | |
| 1. Long table acceleration | RMS | 5g | | |
| 2. Lat table acceleration | RMS | 5g | | |
| 3. Roll table acceleration | RMS | 20 r/s2 | | |
| 4. Pitch table acceleration | RMS | 20 r/s2 | | |
| 5. Yaw table acceleration | RMS | 20 r/s2 | | |
| 6. Vert seat floor accel (Front Rt) | Accelerometer | 5g | | Setra |
| 7. Long seat floor accel (Front Rt) | Accelerometer | 5g | | Setra |
| 8. Vert seat floor accel (Rear Rt) | Accelerometer | 5g | | Setra |
| 9. Vert seat floor accel (Rear Left) | Accelerometer | 5g | | Setra |
| 10. Long seat floor accel (Rear Left) | Accelerometer | 5g | | Setra |
| 11. Lat seat floor accel (Rear Left) | Accelerometer | 5g | | Setra |
| 12. Long seat acceleration butt | X seat pan | | | 15458 |
| 13. Lat seat acceleration butt | Y seat pan | | | 15366 |
| 14. Vert seat acceleration butt | Z seat pan | | | 15365 |
| 15. Vert 2 Seat acceleration butt | Z2 seat pan | | | 12708 |
| 16. Long back acceleration | X seat back | | | 446 |
| 17. Lat back acceleration | Y seat back | | | 446 |
| 18. Vert back acceleration | Z seat back | | | 446 |
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